Symbolic Music Representation in MPEG for new Multimedia Applications

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ABSTRACT

Music is a complex piece of information, although it is usually considered in its audible representation: many notations have been developed over the years and ages to represent visually the information needed by a performer to play the musical work and to produce music as intended by the author. With the spread of computer technology into the artistic fields, new application scenarios for computer-based applications of symbolic music representation have been identified. The integration of Symbolic Music Representation, SMR, in a versatile multimedia framework like MPEG will enable the development of a huge number of completely new applications in several domains of entertainment, edutainment, infotainment, etc., from education and distance learning, to rehearsal and musical practice at home, from consumer electronics like set-top boxes for interactive TV to personal computers and mobiles systems.

Keywords: MPEG-4, Symbolic Music Representation, entertainment, edutainment, music.

Music is a complex piece of information, although it is usually considered in its audible representation: many notations have been developed over the years and ages to represent visually or by other means the information needed by a performer to play the musical piece and produce music as composed and imagined by the author. However music notations are not intended for exclusive use by performers; musical scores are often considered art masterpieces, in the same way as the music they convey, which is especially true for 20th century music.

Symbolic music representation generalizes music notation so as to model, not only the visual aspects of a music score, but also audio information or annotations related to the music piece. Even if not primarily conceived as such, MIDI (www.midi.org) can be considered one of the first Symbolic Music Representation formats; from this point of view, MIDI is good enough to transport music event information (which is its main purpose), yet it cannot produce but unsatisfactory results on the audio and visual representation side.

The evolution of information technology has more recently produced changes in the practical use of music representation and notation, transforming them from a simple visual coding model for sheet music into a tool for modeling music in computer programs and electronic devices in general. As a consequence, symbolic "music representation"/ "music notation" is currently used for several different purposes, other than sheet music production and music teaching; namely it is used also for audio rendering, entertainment, music analysis, database query, performance coding, etc.

Music representation is not only changing with respect to its purely music-related use; associated applications are rapidly evolving with the integration of multimedia and interactivity aspects; with the spread of computer technology into the artistic fields. Completely new scenarios for computer-based applications of symbolic music representation have been identified (see Fig.1) such as: (i) multimedia music for music tutoring systems such as: IMUTUS [11], MUSICALIS [12], etc.; (ii) multimedia music for edutainment and infotainment, for archives like in WEDELMUSIC [13] or for theaters like in OPENDRAMA [14]; (iii) cooperative music editing in orchestras and music schools, as in the project MOODS [15], [16].

A new concept of multimedia interactive music is growing more and more, thanks to new devices and products and also with the help of several innovative R&D projects supported by the European Commission, like the above mentioned ones and more recently the MUSICNETWORK center of excellence (http://www.interactivemusicnetwork.org). All these new applications are taking advantage from media integration and the distribution via Internet, satellite data broadcast, etc., to reach a large number of final users. Many of the above mentioned new tools and applications are beginning to receive the market's attention and interest. Industry is starting to address massively the market with some innovative features, especially in the area of music education: Freehand [25], Yamaha tools [26], Sibelius Music Educational Tools [27], Coda solutions (http://www.finalemusic.com/), etc.

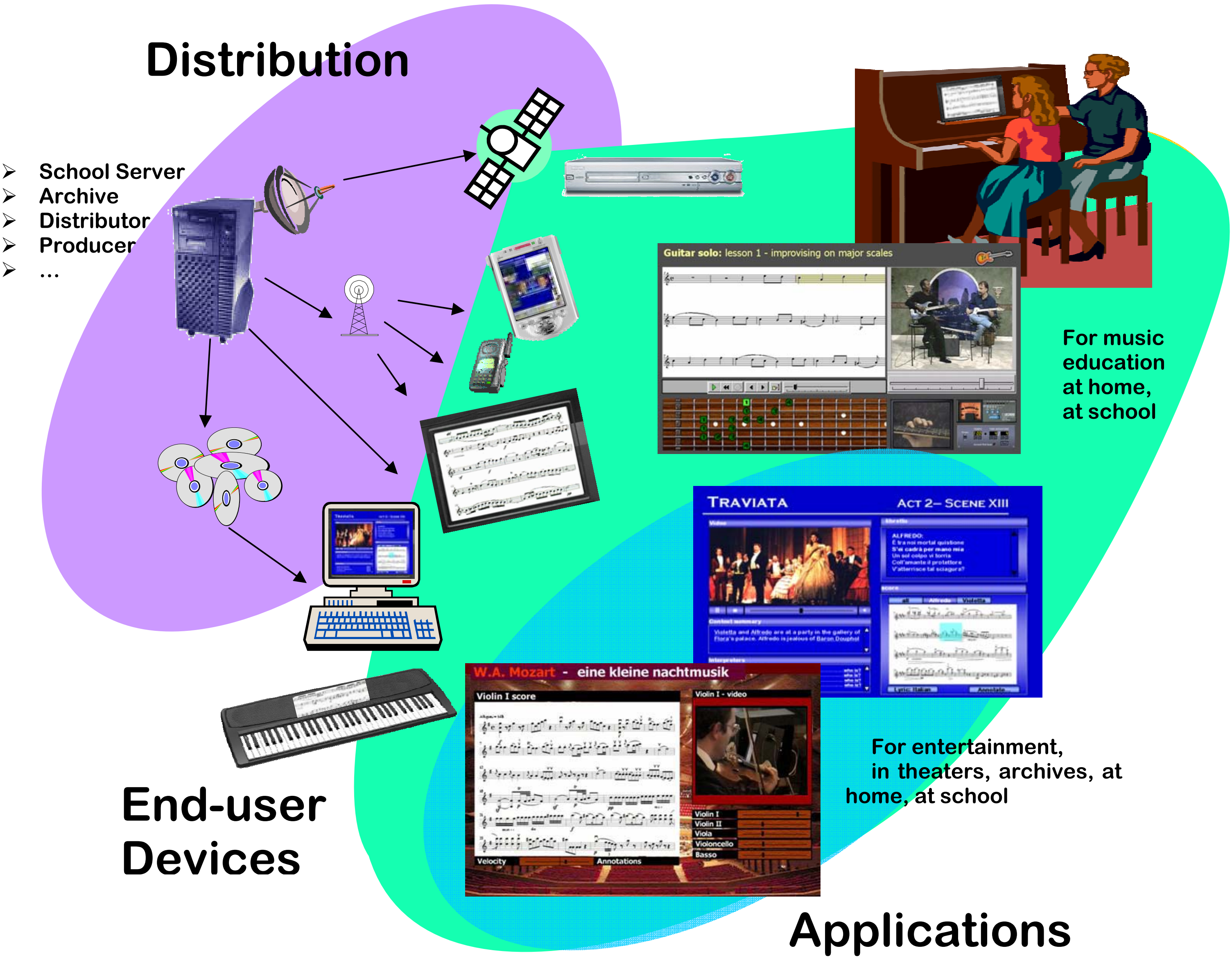

Fig.1 – General scenarios for MPEG SMR in entertainment and education. MPEG-4 with SMR support distribution by means of satellite data broadcast, internet, wireless or traditional communication and storage towards theatres, homes, archives, to devices such as i-TVs, tablet PCs, PCs, PDAs, smartphones.

Among the several possible computer-based applications of music, the notation editing for professional publishing and visualization is one of the most traditional and in many cases too much focused on the visual rendering of music symbols [2], [6], [7], (see also many commercial applications of: Sibelius (http://www.sibelius.com), Coda (http://www.finalemusic.com/), Capella [19], Notion Music [24], etc.). Music publishing requires the production of high quality music scores in terms of number of symbols and their precise placement on the staff. We have observed in the last years a rising use of several XML compliant mark-up languages for music modeling, including: MNML (Musical Notation Markup Language), MusicML, MML (Music Markup Language), MusicXML [17], WEDELMUSIC [18], CAPXML [19], etc. Most of them are mainly focused on modeling the music elements to represent and interchange them among other applications. Only a few of the above mentioned formats can cope with the emerging needs of the innovative multimedia music interactive applications. They are mainly based on proprietary and incompatible technologies where the music content is reshaped for each tool, and for which the information exchange among tools is difficult and strongly limited to the notational part. The lack of standardized formats to enable a symbolic representation of music arouse problems with developers implementing their own solutions that are highly variable in efficiency, scope, features, quality, and complexity. Some previous attempts to standardize music notation were done in the past with SMDL [20] and NIFF [21].

This can be put in a BOX with related bibliography.

Users have discovered the multimedia experience, and therefore the traditional music notation model has in many cases been replaced with more suitable multimedia representations of music such as those needed in the aforementioned cases. The music community and industry need a possibly unique and comprehensive representation of music information, integrated with other media. In order to realize these different applications, we have to take into account several aspects ranging from information modeling to integration of the music representation with other data types. The main problems are related to the organization of music semantics and symbols in a suitable and acceptable form to cope with the more general concepts of music elements and their relationship with audio visual aspects and content.

In addition to these problems, it is also becoming of paramount importance the capability to represent non-western music notations, such as those from the Far Eastern countries (China, Korea, Japan…), as well as Middle East, and Northern Africa. In order to support the inclusion of these music representations, the model has to be kept sufficiently open and general. Furthermore, educational aspects have also a strong influence on requirements for effective music representation models, since they need to integrate semantics information for rendering/playing and performance evaluation at the music elements' level. The mere problem of notation modeling with its related rendering through computer systems has been addressed many times – [1-10].

Symbolic Music Representation

A symbolic representation of music is a logical structure based on symbolic elements representing audiovisual events; the relationship between those events; and aspects related to how those events can be rendered. There are many symbolic representations of music including different styles of Chant, Renaissance, Classic, Romantic, Jazz, Rock, Pop, and 20th Century styles, percussion notation, as well as simplified notations for children, Braille, etc.

The integration of Symbolic Music Representation, SMR, in a versatile multimedia framework like MPEG, with technologies ranging from video and audio, to 3D scenes, interactivity, and digital rights management, will enable the development of a number of new applications like those mentioned previously.. In this way, users can load and/or receive music notation integrated with multimedia in several consumer electronic devices, so as to manipulate music representation to a certain extent: addition/deletion of symbols, transposition, reformatting, etc., without infringing the copyright laws. At present, tools for applications integrating multimedia with music notation are based on proprietary formats. The introduction of an "MPEG" SMR may offer the possibility to move some relevant complexity from software tool development to the content model, so that the same content including SMR can be re-entered by standard tools on a larger number of devices. This will increase the market potential for all the new music applications mentioned e.g. in the previous section. On such grounds, the MUSICNEWORK addressed the MPEG committee to propose a new work item for integrating Symbolic Music Representation into MPEG standard formats (MPEG-4 mainly, but not only).

MPEG SMR will enable the synchronization of symbolic music elements with audio-visual events that can be represented and rendered using existing and already standardized MPEG technology. The breadth of MPEG standards for multimedia representation, coding, and playback, when integrated with SMR through an efficient collaborative development will provide increased content interoperability in all MPEG SMR compatible products; they could exchange and render SMR codes in a secure, efficient and scalable manner.

MPEG SMR is trying to open the way for all the new applications summarized in Fig. 1. Many music-related software and hardware products are currently available in the market and they may greatly benefit from it, since it will foster new tool development by allowing highly increased functionality at reduced costs. Examples of applications that may rapidly be affected by this increased functionality include:

- Interactive music tutorials
- Play training, performance training
- Ear training
- Compositional and theory training
- Multimedia music publication
- Software for music management in libraries (music tools integrating multimedia for navigation and for synchronization),
- Software for entertainment (mainly synchronization between sound, text and symbolic information),
- Piano keyboards with symbolic music representation and audiovisual capabilities,
- Mobile devices with music display and editing capabilities.

Information about the ongoing MPEG SMR activity can be obtained from the web pages of the MPEG ad hoc group on SMR (http://www.interactivemusicnetwork.org/mpeg-ahg). A large collection of documents containing requirements, scenarios, examples, and links can be accessed easily..In the next section, we report in details some of the most important application scenarios that can benefit of MPEG SMR.

Application Scenarios of Symbolic Music Representation

Among the several products being currently available in the market and presenting some form of integration of symbolic music representation and multimedia, it is possible to mention tools in the areas of:

- music education (notation tools integrating multimedia, multimedia electronic lecterns for classrooms and lecture halls, music education via i-TV),
- music management in libraries (music tools integrating multimedia for navigation and for synchronization),
- interactive entertainment, such as karaoke-like (mainly synchronization between sound, text and symbolic information),
- piano keyboards with symbolic music representation and audiovisual capabilities,
- multimedia content integrated with music notation on music instruments, mobiles, PDAs, etc.

Some of these innovative applications integrating synchronizations of music notation and other media, 3D virtual reality, are already in the day by day reality in commercial tools such as VOYETRA, SMARTSCORE, PLAYPRO, PIANOTUTOR, etc., or in prototypes coming from research and development projects (OPENDRAMA [14], WEDELMUSIC [13], MOODS [16], IMUTUS [11], etc.). All these applications of interactive multimedia music representation take advantage of MPEG technology for the standard multimedia integration and for the possibility of distributing content in a variety of forms in a completely integrated manner, see for example [13], [18]. The distribution of multimedia music content can be used to reach the mass market on i-TV, mobiles, media centers, and personal computers for applications of education, edutainment, entertainment, infotainment, etc., ,

Multimedia Music for Entertainment and Infotainment

One of the most interesting applications is the multimedia music publication, for supporting entertainment, interactive music tutorials, multimedia music management in libraries, archives, and theatres. Examples of these applications are WEDELMUSIC [13], OPENDRAMA [14], etc. In these cases, we can see the integration of some symbolic music representation with audio, lyrics, annotations, different visual and audible renderings (different notations, parts and main scores, ancient and common western notation), synchronization with audiovisual such as video, audio, images, etc.

For example, in the case of a multimedia music application for the fruition of lyric operas, like in OPENDRAMA [14], the application can show the music score synchronized with a video of the opera or with a virtual reality version allowing the user to (see Fig.2):

- follow the music by reading the score of the instruments or of the singers and possibly selecting the lyric in a different language.
- read the libretto and its possible translation,
- read and understand the plot which is really intricate in some cases,
- add personal annotations on the music, to mark a particular passage

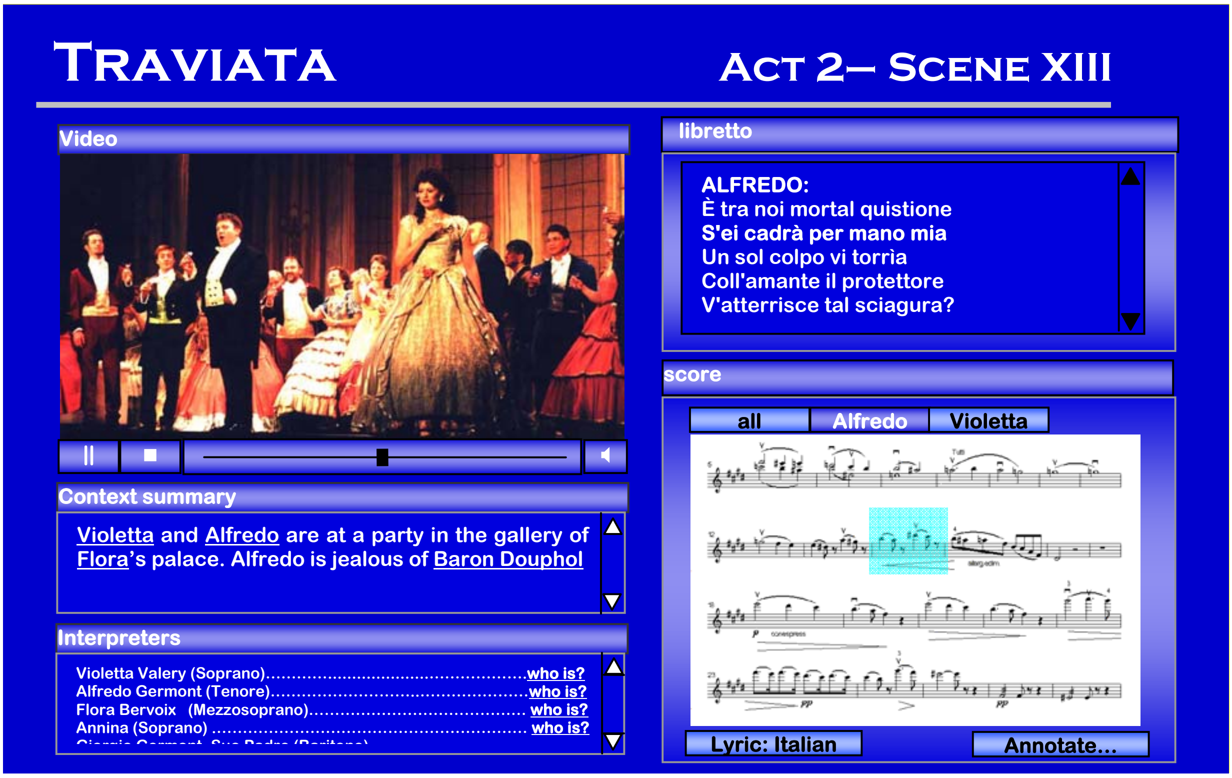

Fig.2 – A mock-up of a tool exploiting MPEG SMR for entertainment, edutainment, suitable for theatres, i-TV, archives, PC, etc., coded in MPEG-4 with SMR support.

An application like this may be used inside a theater from a palm top installed in the stalls, allowing the user to follow what is happening on the stage or can be used on i-TV or PC for entertainment and edutainment.

SMR for Educational and Edutainment

Another interesting application is the exploitation of MPEG SMR to support educational or edutainment applications. Examples of these applications are MUSICALIS, IMUTUS, WEDELMUSIC with authoring support. In these cases, we have the integration of SMR with audio, lyrics, annotations, different semantics for visual and audible renderings (different notations, parts and main scores, ancient and common western notation), synchronization with audiovisual such as video, audio, images, and also the 3D virtual rendering of the position of the hands and body (posture and/or gesture), or of the scene with the actors, etc. (see Fig.3).

Music education and edutainment are the largest markets for music representation. In the same way a text can be synchronized to images and sounds in commercial DVDs, audio, video and music representation can be synchronized as well, for various (or separate) instruments and voices, and with various models or rendering aspects (common western music notation, tablature, Neumes, Braille, etc). Therefore, it is strongly desirable to be given the possibility of distributing content in different forms, though related to the same piece of music. For music education and courseware construction, music notation needs to be integrated with multimedia capabilities. About 80% of young students are involved in music studying; this implies that a large part of them can read some music representation and play an instrument to a certain extent.

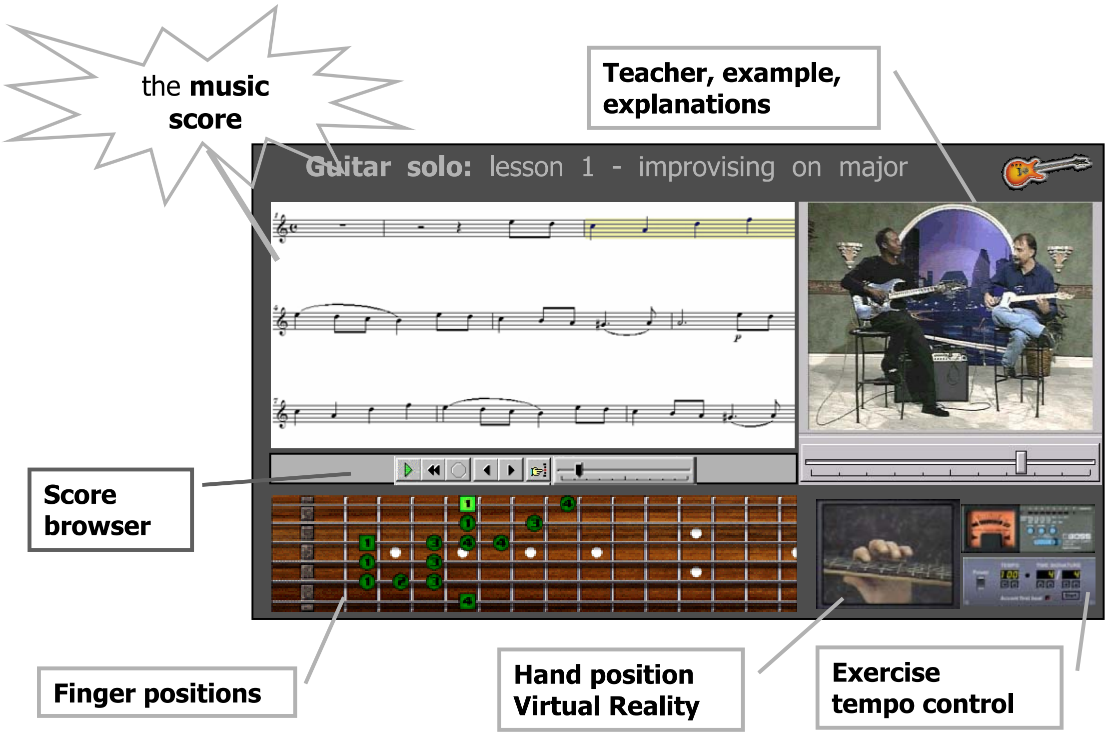

Fig.3 – A tool mock-up for exploiting MPEG SMR for education, edutainment, suitable for assisted learning, self-learning, on i-TV, tablet PC, etc., coded in MPEG-4 with SMR support.

Music coursewares need to have music representation integrated with video, images, documents, animation, audio, video, etc. In addition, a music course may present some exercises which require special music notation symbols (e.g., given by the teacher for the student, user defined) and/or audio processing (e.g., play training assessment, theory training assessment, etc.). For these reasons, for music education and courseware production the users on both the client (music content usage) and server (content generation) side have a visual representation of the musical model (with full access to logical aspects and additional semantics information for visual and audio rendering), with full capabilities of music manipulation and a support for the synchronization and for establishing relationships with other media. Therefore, system and model have to provide the possibility of:

- navigation among music representation features and multimedia aspects and content. The user could browse a music representation and follow hyperlinks associated with music symbols/entities. The hyperlinked content could be external (a URL) or internal (an MPEG-4 audio visual element). The content associated with a music symbol could be a video/image/text explaining a difficult passage, its semantics, the aim of the composer, etc.;
- music editing, this may imply the dynamic alteration of the logical, audio and visual domains of symbolic music;
- transposing, this may imply the dynamic alteration of details in the logical, audio and visual domains of symbolic music;

- playing, this may imply the interpretation of symbolic music representation to produce for example a visual rendering with some scrolling and a synchronized audio;
- formatting, this may imply the dynamic interpretation of symbolic music representation to produce a rendering in the visual domain, depending on the screen/window size;
- reducing music notation to piano; this may imply the dynamic alteration of aspects in the logical, audio and visual domains of symbolic music;
- selecting one lyric from the collection of multilingual lyrics for the same music representation; lyrics with music notation synchronized with video or audio (music karaoke, vocal and ear training);
- synchronization of audio visual events with the music representation elements, so as to show in a visual manner the correct point where music is played, score following, etc. This requires the presentation of the visual aspects of music synchronized with the audio possibly allowing for changing the velocity of the performance, the adjustment of different playing parameters, etc. Executing the audio of the teacher or a famous musician with the visualization of the preferred music representation;
- showing the video of the teachers or showing the 3D rendering of the correct gesture of the hands, while playing the instrument synchronously with the music notation;
- playing along: automatic accompaniment of the user by having the computer play selected voices/parts. This can be performed by using real audio recorded, generating MIDI, or by a more sophisticated music notation rendering. The system can follow automatically the pupil's performance and produce comments and corrections on-line or off-line;
- specifically formatting music for rendering on different devices, or with different resolutions, or for rendering music representation in a different formats and on different devices: Braille, tablature, guitar tablatures, spoken or talked music, Korean music, etc. For example, talked music is useful when non experts work on music notation editing, the tool may be of great help for their editing work by producing a verbal description of the music context they are editing, and mentioning also what they add, i.e. "*measure 45, quarter chord of a D and a C flat in arpeggio, ….*". This rendering model is a slang to describe music very useful for impaired, young students, dyslexic people, etc., see for instance http://projects.fnb.nl/Talking%20Music/default.htm .

More interactive and complex players may integrate additional capabilities to support:

- *annotation*, for adding teacher and pupil annotations that may be textual or in music notation, or audiovisual. This also includes capabilities of versioning and the possibilities of attaching complex information and rendering hints to SMR elements;
- *recognition* of notes played by an instrument or voice, using pitch recognition or other technologies. This means that the audio events have to be compared with what is expected by the notation conventions at the logical/symbolic level, and therefore an appropriate visualization is created;
- *assessment* with respect to semantic annotations (how to execute a certain symbol, how to assess a certain execution of a music notation piece from the pupil, etc.). As noticed above, a good level of assessment needs a precise modeling of quality for the main domains of music performance, such as pitch, rhythm and sound. Particularly, sound quality, as well as detailed prescriptions on physical gesture should be made available;
- *cooperative work* on music notation for classes, for orchestral work on music lecterns (e.g., Tablet PCs), for managing rehearsals, etc.;
- *customization of SMR rendering* according to the needs of the individual (for example, selecting symbols to be verbally described or printed, or played, selecting a simpler model for the visualization or playing, for example without beaming, without ornaments, etc.);

Integration of SMR in the MPEG framework

Already standardized MPEG tools are not yet able to support symbolic forms of music representation in a systematic and satisfactory manner. Indeed, the MPEG-4 technology covers a huge media domain. In particular, the Audio part of this standard offers the possibility to include standard MIDI content synchronized with other forms of coding; it allows structured descriptions of audio content through a normative algorithmic description language associated with a score language more flexible than the MIDI protocol (MPEG-4 Structured Audio, or SA). These tools, though allowing to *derive* in someway a symbolic representation out of the information they carry, are to a large extent not enough to guarantee a correct coding of notation, as they lack for instance of any kind of information about visual and graphic aspects and many symbolic details, a thorough music notation modeling and many necessary hooks for a correct human-machine interaction through the SMR decoder. MPEG-7 also provides some symbolic music related descriptors; but they are not meant to be a means for coding SMR as a form of content. On the other hand SMR content can actually be a complete representation in itself and it may be somehow rendered in synchronization with other audio-visual elements.

The integration of SMR in MPEG completely satisfies the requirements of the scenarios described above and many more, permitting such tools to integrate with the powerful model of MPEG for multimedia representation, coding and playback. At the same time, compliance with the MPEG SMR standard will not require compliance with all MPEG-4 parts and tools. There are in MPEG mechanisms to cope with the complexity of the standard by means of Profiles that could be a way to allow shaping a specific SMR-oriented application with the support of only a few selected MPEG-4 features as it already happens for many other parts of MPEG-4. In fact, the added value of SMR for multimedia music integration goes even beyond the development inside MPEG-4 since its core part can find a usage as a standalone tool also outside the MPEG framework.

Symbolic Music Representation (SMR) will be integrated into MPEG-4 [22] by:

- defining an XML format for a text based symbolic music representation, to be used for interoperability with other symbolic music representation/notation formats and as a source for the production of an equivalent binary information that may be stored in files and/or streamed by a suitable transport layer;
- adding a new Object Type for the delivery of a binary stream containing symbolic music representation and synchronization information; the associated decoder will allow to manage the music notation model and to add the necessary "musical intelligence" for the interaction with humans;
- specifying the interface and the behavior for the symbolic music representation decoder and its relationship with the MPEG-4 synchronization and interaction layer (Systems part, Binary Format for Scenes or BIFS nodes, advanced graphics extensions).

Figure 4 shows an example about the usage of symbolic music representation during the authoring phase, which highlights the central role of the MPEG-SMR XML format. The SMR XML content can be produced using appropriate converters and/or a native SMR Music Editor. Then, an MPEG-4 SMR-enabled encoder tool can multiplex the SMR XML file into an MPEG-4 binary file (standard XML binarization is also available in MPEG). MPEG-4 content can be stored or distributed as a binary stream to clients. The SMR binary stream contains information about music symbols and their synchronization in time and space. A decoder in the user's terminal (player) converts this stream into a visual representation, which can be for instance rendered in the BIFS scene.

Figure 5 reports a simple example of an MPEG-4 Player supporting MPEG-4 SMR. The SMR node in the BIFS scene is used to render the symbolic music information in the scene (this could be performed by exploiting functionality of other BIFS nodes) as it is decoded by the SMR Decoder. The end user can interact with the symbolic music representation (change page, change view, transpose etc.) through the SMR interface node, using sensors in association to other nodes defining the audiovisual, interactive content. User commands are sent out from the SMR node fields to the SMR decoder (dashed lines), which generates a new view to be displayed in the scene.

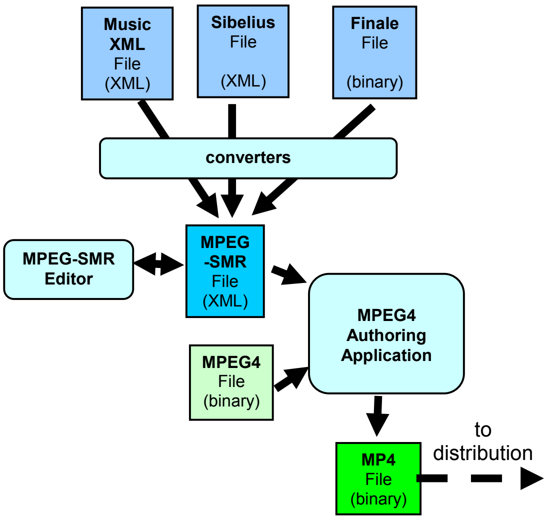

Fig. 4 -- SMR in the authoring phase

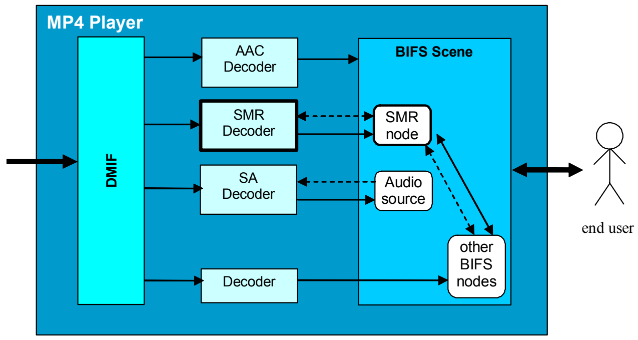

Fig. 5 -- SMR inside an MPEG-4 Player

The structure of the SMR decoder (see Fig.6) includes:

1. the **Binary decoder** decodes the binary stream coming from the MPEG-4 DMIF (Delivery Multimedia Integration Framework) interface or from an MPEG-4 file. The decoder extracts the optional SMR rendering rules and the synchronization information from the SMR access units, loading the SMR Rendering Rules data structure to any SMR Rendering Rules engine, and sending the synchronization info to the SMR Manager;
2. the **SMR Model** includes only symbolic music representation parameters, while the images, audio, video, etc. (other object types) are simply referred to other MPEG objects;
3. the **SMR renderer**, controlled by the *SMR Manager*, uses the *SMR Model* with its *parameter values* and the *SMR Rendering Rules* to produce a view of the symbolic music information in the SMR Decoder Buffer. The rendering part of the SMR in the visual domain is mainly based on WEDELMUSIC solution that can be recovered in [28]. It is based on modules of music justification and symbols positioning that work together in order to arrange the placement of symbolic music representation symbols on the page or screen according to different parameters such as: page size, justification values, formatting rules and style, etc.
4. the **SMR Decoder Buffer** may contain pixels and/or vector graphics information. This may be a solution dependent issue; the graphic functionality of BIFS (or equally of its textual format XMT-A) is partially overlapping with that of SVG, which is actually being used already as a tool to implement the graphic layer of symbolic music;
5. the **SMR Manager** coordinates the behavior of the SMR decoder. It (i) receives and interprets the events coming from the SMR node interface. According to the command type, it can modify parameters in the SMR Model (e.g., transposition) and/or control the SMR Renderer (e.g., change view, change page, etc.), and (ii) it controls the synchronized rendering using the synch info;
6. the **SMR node** and **other BIFS nodes** produce Composition Buffers (see point 4 above). SMR node specifies the interface events to the rest of the BIFS scene and to the user.

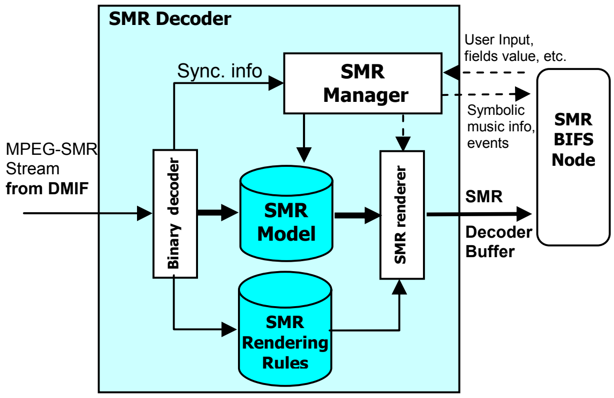

Fig.6 – The structure of a MPEG SMR decoder

In MPEG-4 integration and synchronization in time with other media rely on the concept of Access Unit (AU), defined as an individually accessible portion of data within an elementary stream. An Access Unit is the smallest data entity which timing information can be attributed to, by the System (e.g., also media synchronization) layer.

Encoding of SMR into the bitstream and in the AUs, may be achieved in three different ways:

1. part (or all) of the SMR synchronization information (i.e., time labels associated to "events") can be included in the header (ObjectTypeSpecificInfo);
2. SMR synchronization information can be inserted in AUs with embedded timestamps, thus, it is possible to deliver certain AUs with content intended for a later use;
3. SMR synchronization information can be inserted in AUs without embedded timestamps; in this case the decoding timestamp of the AU is the reference time and events to be scheduled immediately upon reception.

Each of the above three possibilities can be associated with different use cases. In some situation, content is more or less available (reasonably) before its playback and everything can be coded. In other situations, this is not possible/reasonable and the use of AUs is required (for instance if the performer is playing a MIDI device in real-time and transmitting it in a stream).

A particular care is dedicated by SMR to the relationships with MIDI information; if a publisher wants to use some MIDI files only in MPEG-4 compliant devices (this is possible through the simplest Object Type defined in the Structured Audio subpart) and if these devices support SMR visualization, the specification will permit MIDI files to be automatically converted (through some specific algorithm) into SMR on the client side and rendered. Similarly only the SMR may be available and delivered. In those cases, the MIDI information can be generated on the client side from SMR to be used with MIDI compliant devices. This is particularly important to guarantee straightforward adaptation of current devices.

Conclusions

Integration of symbolic music representation (SMR) in multimedia frameworks, and particularly in MPEG, is opening the way to the implementation of a large set of new applications in the areas of education, entertainment and cultural valorization. Most of these applications are not available yet on devices accessible to the end user such as interactive TV, mobiles, etc., and those available on PC are not based on standard content formats, thus constraining producers to reshape any functionality from scratch by creating specific tools. This is a strong limitation for the diffusion of music knowledge and for the educational market of music. The integration of SMR in MPEG will permit to code and distribute new extended functionality that will be accessible for a larger number of citizens enabling the development of a number of innovative applications, from distance learning, to rehearsal and musical practice at home, and any imaginable form of music enjoyment on any kind of end user devices like those mentioned above.

Some of these new application scenarios have been presented in this paper, and issues related to integration in MPEG have been discussed. We have shown one of the many possible forms of integrations, and that music and more precisely any music notation could benefit greatly from this integration. Conversely, SMR may become a way for multimedia frameworks and particularly MPEG to express a great potential in the domain of music enjoyment and end user entertainment, joining in new directions education, leisure and cultural activities.

Further information on MPEG SMR can be recovered from the web pages of the MPEG ad hoc group on SMR [23]: http://www.interactivemusicnetwork.org/mpeg-ahg. A large collection of documents which contain requirements, scenarios, examples, and links can be accessed easily.

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